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Effects of a Novel Cooling Shirt on Various Physical Performance Parameters in Elite Athletes



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14. ABSTRACT Elite athletes, as well as military personnel, are routinely exposed to a variety of high-heat conditions that can ultimately alter judgment and physical performance and even result in death. The reductions in physical performance could severely limit the ability of athletes and soldiers to sustain and satisfactorily continue the high level of performance often required during intense ground operations and sport matches. The primary purpose of this short-term field observation was to determine the effects of a technical cooling shirt and physiological sensor technology in the field on various physiological parameters on Division I collegiate football players. Twelve National Collegiate Athletic Association Division I football players, of various positions, were selected to participate in a non-human use field observation to evaluate a novel cooling shirt and Zephyr BioHarness™ on eight separate days. The lower leg resistance training sessions' rating of perceived exertion was significantly higher in the "loaded" cooling shirt containing a cooling material than the "unloaded" condition containing no cooling material (p=0.001). In the sprint interval workouts, the athletes in the loaded conditions achieved a higher average sprint speed in comparison to the unloaded conditions (p=0.01). Based on the outcomes of this study, additional field studies are warranted while subjects engage in high-intensity activities. Additionally, future research should be conducted to test the cooling material in varying environments such as dry heat and very hot, humid conditions with the cooling shirt worn alone and with the cooling shirt covered.					
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1.0 SUMMARY

Heat-related illness is a debilitating condition suffered by those operating in hot, humid environments that can alter physical and cognitive performance and lead to mishaps in military operations. Adverse effects attained from heat illness may be prevented with proper training and the utilization of appropriate cooling devices. Current cooling devices such as vests, bandanas, and neck-cooling devices may be bulky and frequently require ice or gels, which are impractical for operators who must carry heavy gear for long distances in hot, humid conditions. Additionally, the cooling effects of the majority of cooling devices are neither significant nor sustained. This study evaluated the effects of a novel cooling shirt, which was previously determined in laboratory testing to provide 2 hours of sustained cooling, on physical performance in 12 National Collegiate Athletic Association Division I football players with similar anthropometrics and physical workloads as U.S. Air Force Special Operations Forces. Physiological data were collected during 2 weeks of summer preseason football training. Subjects performed 1 week of workouts with cooling inserts “loaded” into the shirt and 1 week of workouts without cooling material inserted into the shirt (“unloaded”), with the order of the cooling conditions randomized between weeks. Subjects were required to wear team-issued shirts over the cooling shirt in both conditions. Weekly workouts consisted of a combination of strength training, speed training, and agility and were similar in duration, intensity, and mode between corresponding days for each week. Physiological parameters that were measured during this 2-week observation included the following: (1) exercise heart rate, (2) sprint speed (acceleration), (3) heart rate variability, (4) subjective rating of perceived exertion, (5) peak heart rate, and (6) cooling shirt performance questionnaires. Rating of perceived exertion was significantly higher in the loaded cooling shirt condition than the unloaded ($p=0.001$) during lower body strength training. Average acceleration ($p=0.01$) and average heart rate ($p=0.01$) were significantly higher during outdoor sprint intervals in the loaded condition. No other significant differences were found between conditions. Based on the findings of this study, additional field studies are warranted while subjects engage in a high-intensity activity. Future research should be conducted to test the cooling material in varying environments such as dry heat and very hot, humid conditions with the cooling shirt worn alone and with the cooling shirt covered.

2.0 INTRODUCTION

Battlefield Airmen are an elite group of soldiers, trained to endure the worst possible conditions and environments on the battlefield, and are required to push the human body to its limits. The physical prowess of these soldiers has been compared to elite athletes. The physical demands required during training and battle, the types of clothing and protective equipment worn, and dehydration all contribute to heat-related illness in both elite athletes and soldiers.

Heat-related illness is a debilitating condition suffered by those operating in high-heat environments that can alter judgment and physical performance. Battlefield Airmen, as well as elite athletes, suffering from heat illness may experience reductions in physical and cognitive performance. The reductions in work capacity could severely limit these individuals’ ability to sustain and satisfactorily continue a high level of performance required during intense ground operations and sport matches.

Physical training techniques that aid in the prevention of heat stress include heat acclimatization and the supplementation of fluids before and during vigorous physical activity. These physical training techniques, similar to those used by elite athletes, are normally included into military training programs and aid in lowering resting and exercise core body temperature as well as conserving blood plasma volume [1]. Based on previous research, acclimatization to the heat requires an individual to engage in intense exercise (heart rate (HR) >85% of age-predicted max HR) for a minimum of 6 days, while very fit individuals may require less time (approximately 4 days) to become acclimated to the high-heat environments [1,2]. Once these individuals become acclimated to the heat, 3-27% increases in blood plasma volume help maintain sweating capacity and stroke volume [1,2]. Additionally, physiological benefits such as reduced blood flow to the skin and increased central blood volume also occur [2].

The positive effects of the training techniques previously mentioned can be insufficient when an individual performs high-intensity physical activity in the heat for prolonged periods. When skeletal muscle contractions are combined with excessive heat stress, the cardiovascular system can be pushed to the limit to support the competing thermoregulatory demands of blood flow to the skin and the metabolic demands of the contracting skeletal muscles. As a result, environmental heat stress and skeletal muscle contraction interact synergistically, leading to degradations in human performance and inducing heat illness [3].

The primary purpose of this 2-week field observation was to determine the physiological effects of a novel cooling shirt during high-intensity physical activity of Division I athletes. The researchers hypothesized that the cooling shirt technology would result in lower exercise HR, peak HR, and rating of perceived exertion (RPE) than the shirt without the cooling technology when comparing similar workouts. Additionally, these researchers monitored physiological variables using an advanced physiological monitoring device known as the Zephyr BioHarness™ (Zephyr Technology Corp., Annapolis, MD). The BioHarness™ 3 is a compact physiological monitoring device that captures the comprehensive physiological data on the athlete via mobile and fixed data networks. This is beneficial to researchers because it allows remote monitoring of human performance in “real” world conditions [4].

3.0 BACKGROUND

During war and training, both elite athletes and soldiers are subjected to a variety of environmental conditions that can alter judgment and physical performance and even result in death. These adverse conditions may impair physical and cognitive performance, which severely limit the athlete or soldier’s ability to satisfactorily complete specified mission requirements during intense ground operations.

Heat stroke, which results from excessive heat stress impairing the hypothalamus’ ability to regulate body temperature, is a dangerous concern for the athlete or soldier. This impairment results from an inability to regulate the core body temperature [5,6]. Core body temperatures greater than 41°C may result in mental confusion, dry skin, delirium, convulsions, and unconsciousness [7,8], while the estimated death rate for heat stroke is 20% [5].

The adverse effects attained from heat stress could result in mission mishaps but can be prevented with proper training and appropriate cooling devices in detrimental hot, humid environments. When heat accumulation exceeds removal in the brain, temperatures may exceed 40°C, potentially impairing the ability of athletes and soldiers to sustain normal work intensity [9]. Additionally, mean brain temperature is estimated to be 0.2°C higher than core body

temperature during sustained aerobic exercise in either normal or hot, humid conditions, ultimately impairing cognitive ability [10]. Failure to train troops correctly for high-heat environments or to use appropriate cooling devices can result in mission mishaps. For example, the incapacitation of a soldier suffering from heat-related illness requires up to four members of a squadron to carry him or her to a safe location [7]. Therefore, proper heat management is paramount to preventing mishaps and improving performance in the field.

Current cooling devices, such as vests, bandanas, and neck-cooling towels, either must be frozen or contain a form of cooling crystals or gel packs that are enclosed within a fabric and are activated by soaking in water or by pressing a sensor attached to the cooling vest. The cooling effects provided are minimal and are not sustained, especially when ground troop soldiers are exposed to hot, humid conditions for long periods. Furthermore, cooling vests typically require a generator to be worn in the backpack to sustain a continual cooling effect. The water or gel necessary for the cooling vest adds additional weight. Current devices to prevent heat illness are therefore ineffective for soldiers and athletes exposed to extremely hot, humid conditions. The new cooling shirt may serve as a more practical cooling device that could be used by entire ground units because of its cooling effectiveness, portability, weight, and ease of use in the battlefield.

The cooling shirt being evaluated in this study was previously determined to provide sustained cooling effects for longer than 2 hours on a thermal manikin in a laboratory setting. The initial research was conducted under dry heat conditions at 35°C/50% relative humidity as the first step to evaluate the technology. Additionally, the cooling shirt reduced core body temperature in a laboratory setting. Therefore, the next step in the evaluation process was to conduct a field test on a population with physical characteristics similar to Battlefield Airmen.

4.0 METHODS

Twelve National Collegiate Athletic Association Division I football players, of various positions were selected to participate in a non-human use study to evaluate a cooling shirt in the field (Table 1).

Table 1. Descriptive Statistics of the Study Population

Statistic	Value	SD (±)
Age (yr)	19.9	1.1
Height (m)	1.85	0.07
Weight (kg)	96.6	11.5
Body Fat (%)	6.4	2.3
40-yd Dash (s)	4.55	0.13
Vertical Jump (in)	31.7	2.6

SD = standard deviation.

Subjects were observed during preseason strength and conditioning sessions over two consecutive weeks. Prior to each training session, the subjects were appropriately fitted with a moisture-wicking shirt. The shirt was developed by a team of U.S. Air Force School of Aerospace Medicine researchers in conjunction with Russell Athletic under a Cooperative Research and Development Agreement in 2012. The shirt was designed with sewn-in pockets

(Figure 1) to hold specially cut-to-size cryotherapy material in place. The subjects were then counter-balanced, with half of the subjects “loaded” with the cooling material placed into the sewn-in pockets of the moisture-wicking shirt during the first week. The other half of the subjects were “loaded” during the second week. Each group was “unloaded” in the opposing week, wearing the moisture-wicking shirt without the cooling inserts. The loaded subjects were equipped with the cooling material 10 minutes prior to the start of their workouts, while the unloaded subjects were given only the moisture-wicking shirts with no cooling inserts. Each subject wore a Zephyr BioHarness™ to record heart rate and acceleration data during all training sessions. The cryotherapy inserts and Zephyr BioHarnesses™ were inserted and programmed by trained staff to ensure athletes were properly fitted.



Figure 1. Moisture-wicking cooling shirt with sewn in pockets.

The two weeks this group of investigators chose to use for data collection were selected based on similarities in the workouts between days of the week to provide a better comparison for the “loaded” vs. “unloaded” conditions (Table 2). For example, the Monday morning sessions consisted of similar drills, exercise intensity, and duration during Weeks 1 and 2. The venues were a combination of indoor and outdoor facilities traditionally used by the team for practice and strength and conditioning sessions. Indoor and outdoor climate conditions were measured and recorded with an electronic device immediately following each workout session.

Table 2. Description of Workouts

Workout Day	Description
Monday a.m.	Dynamic warmup; 20-yd start drills on indoor turf, upper body lift
Monday p.m.	Dynamic warmup; speed and agility session on indoor turf
Tuesday a.m.	Dynamic warmup; lower body lift
Thursday a.m.	Dynamic warmup; upper body lift
Thursday p.m.	Dynamic warmup; outdoor sprint workout
Friday a.m.	Dynamic warmup; total body lift, functional circuit on indoor turf

Physiological variables including exercise HR, acceleration, HR variability, and peak HR were measured using the Zephyr BioHarness™ and compiled according to loaded and unloaded conditions for statistical analysis. The subjects’ RPE for the exercise session was reported following each workout using a 6-20 Borg scale, with 6 being “no exertion at all” and 20 being “maximal exertion.” Subjective data about the product were collected at the end of each week with Likert scale questionnaires on a 1 to 5 scale, 1 being unfavorable and 5 being favorable responses (Figure 2).

5.0 RESULTS

The air temperature and types of training between the two weeks of the study were similar. There were no significant differences ($p>0.05$) between the air temperature, humidity, or duration of the selected workouts from day to day between the two weeks. There were no significant differences between the average HRs or peak HRs of any of the workout days (Table 3).

The RPE during lower body strength training was significantly higher in the loaded cooling shirt condition than the unloaded ($p=0.001$). However, in the outdoor sprint workout, the loaded condition resulted in a significantly higher average speed (acceleration) when compared to the unloaded condition ($p=0.01$). Additionally, the outdoor sprint workout resulted in a significantly higher average exercise HR in the unloaded condition compared to the loaded ($p=0.01$).

1. Please rate your overall satisfaction with the cooling shirt.

Poor below average average above average excellent

2. The cooling pads were easy to insert into the pockets.

Strongly disagree disagree neither agree or disagree agree strongly agree

3. The cooling pads stay in contact well with the body.

Strongly disagree disagree neither agree or disagree agree strongly agree

4. The cooling shirt conforms well to the body.

Strongly disagree disagree neither agree or disagree agree strongly agree

5. The cooling pads provide sufficient body surface coverage.

Strongly disagree disagree neither agree or disagree agree strongly agree

6. The cooling shirt feels like it will cool your body.

Strongly disagree disagree neither agree or disagree agree strongly agree

7. The cooling shirt improved my performance.

Strongly disagree disagree neither agree or disagree agree strongly agree

8. The cooling shirt did not interfere with my body armor or other required operational gear.

Strongly disagree disagree neither agree or disagree agree strongly agree

9. The cooling shirt exceeded my expectations.

Strongly disagree disagree neither agree or disagree agree strongly agree

10. The cooling shirt felt like it wicked water away from my body

Strongly disagree disagree neither agree or disagree agree strongly agree

11. The cooling shirt provided a sustained cooling effect

Strongly disagree disagree neither agree or disagree agree strongly agree

Additional Feedback

1. Would you be happy/feel comfortable using a cooling shirt like this? If not, why?
2. How would you improve this product?
3. Is this product in need in your line of work?
4. Did it cause any discomfort? If so, explain how and where.
5. Is there another cooling device you would like to see/use?

Figure 2. Cooling shirt feedback questionnaire.

Table 3. Mean Physiological Variables per Workout Session

Variable	Monday				Tuesday		Thursday				Friday	
	AM		PM		AM		AM		PM		AM	
	Loaded	Unloaded	Loaded	Unloaded	Loaded	Unloaded	Loaded	Unloaded	Loaded	Unloaded	Loaded	Unloaded
HR (BPM)	132.1	132.1	138.1	148.5	131.9	130.4	121.6	127.2	149.6	155.2 ^a	129.2	129.4
Acceleration (m/s)	0.56	0.56	0.80	0.83	0.70	0.69	0.42	0.45	0.84	0.95 ^a	0.64	0.63
HR variability	32.3	31.6	30.5	29.2	37.9	36.7	36.6	38.4	36.9	30.9	38.9	36.9
Workout time (min)	117.4	137.0	74.3	73.2	90.2	94.0	94.3	100.8	61.5	56.5	106.9	104.5
HR (BPM)	188.8	194.4	189.7	196.8	184.1	179.3	176.2	197.5	201.8	205.9	189.4	176.4
RPE	13.67	13.67	13.88	14.00	16.25	14.36 ^a	14.33	14.42	15.08	15.25	15.58	15.17

BPM = beats per minute.

^aSignificantly different from loaded condition $p < 0.05$.

Based on the subjective data gathered through use of a questionnaire, there was a difference between the loaded and unloaded conditions found in the subjects' response to the ability of the shirt to wick away water. On a 1 to 5 scale of performance, 1 being unfavorable and 5 being favorable responses, the unloaded shirt performed better than the loaded shirt (3.44 vs. 2.56) in this population of athletes in the training field. The cooling technology was determined to be easy to use and insert into the cooling shirt (4.10 ± 0.54) in the loaded condition. Both the unloaded and loaded conditions had slightly favorable responses to the cooling shirt's conformity to the body and staying in contact with the subject, although no differences were found between conditions. The subjects had slightly negative responses to area of body coverage, sensation of cooling effect, and duration of cooling, with responses ranging between 2.3 (low) and 2.7 (high) on the Likert scale.

6.0 DISCUSSION/CONCLUSIONS

The primary purpose of this study was to determine the effects of a novel cooling shirt on performance during high-intensity physical activity of Division I athletes, measured outside of the laboratory setting with a Zephyr BioHarness™. The results of this study were conflicting regarding the effectiveness of the cooling shirt. While the cooling shirt loaded appears to have resulted in lowering exercise HRs during outdoor sprint training, there was a significantly higher average run speed in the unloaded condition. The RPE values on those days were not significantly different between conditions. While this confirmed the original hypothesis of the study, it is difficult to separate the effectiveness of the cooling shirt from the difference in workout run speed. A higher average run speed should have resulted in a higher average HR response. This particular physiological variable was difficult to control in the field in comparison to a laboratory setting.

Interestingly, RPE was statistically higher in the loaded condition during lower body strength training, with no differences in HR between conditions. This could be due to the subject's perception that the loaded cooling shirt workout was more difficult when the workouts themselves were actually very similar in duration and intensity.

Skin and core temperatures were not collected due to the non-human use classification of the study. The skin temperatures collected by the Zephyr were neither reliable nor valid and were therefore not reported. Additionally, the population of the study was not permitted to utilize ingested core temperature pills.

Based on the outcomes of this study, although the cooling technology was effective in the laboratory setting, it did not improve performance of this group of elite athletes in the field. Therefore, these investigators suggest more field-based studies be conducted on a similar group of athletes or Special Operators to determine if particular alterations in the shirt itself need to be made before it can be worn under gear during field operations to mitigate heat-related illnesses. Suggested improvements could include longer lasting cooling materials with greater potency and covering a larger surface area of the body. This particular group of subjects was required to wear a team-issued training shirt that covered the cooling shirt while they trained. This may have caused a lack of breathability that was not found in the laboratory setting, where the cooling shirt was uncovered while subjects performed a rigorous weighted treadmill walking test.

As with any field study, it is difficult to determine whether specific physical training conditions were kept consistent from week to week, as this team of researchers was not present during each training session. While temperatures were not significantly different between the days of the two cooling shirt conditions, humidity did vary between them. This was out of the researchers' control. The workouts performed by the student-athletes were dictated by the strength and conditioning staff and not this particular team of investigators. While the workouts were similar between testing conditions, they were not consistent. This could contribute to the varying results noted during this 2-week field observation.

Future studies should be conducted to test the cooling material in varying environments such as dry heat and very hot, humid conditions. While there were no statistical differences between workouts, a subject pool that had a more pliable workout schedule would benefit the researchers for equalizing the variables. However, during this 2-week observation, this team of investigators was not permitted to supervise any of the training sessions nor dictate what the training session would consist of, which could have also contributed to the varying reported results.

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LIST OF ABBREVIATIONS AND ACRONYMS

HR	heart rate
RPE	rating of perceived exertion